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Preface

Spare parts for drill rigs

Runar Samland

M.S. in Offshore Technology, Asset Management

Supervisor: Sukhvir Singh Panesar and Professor Tore Markeset

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The problem to be address in this thesis is to identify and evaluate a set of parameters to determine the need for spare parts for drill rigs. With emphasis on problems specific for drill rigs study these parameters and their effect on spare part logistics.

The problems with spare parts at offshore drill rigs are an area where continuing improvement can prove worthwhile for most companies in regards to safety, efficiency and profitability.

As a practical study a drilling company operating in the North Sea will be reviewed with regards to handling of spare parts. A description of a computerized tool for maintenance and spare part handling will be made and linked to the use of the mentioned parameters to determine the need, use and problems with spare parts for drill rigs. There will not be any part or item specific details; neither will the computerized systems in use involve details or identifications.

With this master thesis I complete my masters' degree in Offshore Technology asset management at the University in Stavanger. I would like to express my gratitude to my advisors Professor Tore Markeset at University in Stavanger and Sukhvir Singh Panesar at Apply Sørco for their assistance, guidance and recommendations in working on my masters' thesis. In addition to my advisors, I would also like to express my gratitude to Jawad Raza at Apply Sørco, who has provided valuable knowledge and guidance in the use of spare parts in offshore drilling and the use of computerized programs to aid spare part management.

Abstract

Spare parts for drill rigs are a complicated and important task to be handled. The operations are run on tight schedules and costs are based on the number of days to complete the operations. There are strict regulations concerning the safety while running operations offshore, since consequences for both the personnel involved and the environment can be severe. To avoid having to stop the drilling operations it is very important to have a functioning system to provide spare parts if a component breaks down or need maintenance. To further complicate the handling and logistics of spare parts, a drill rig will be located at several different locations during its life time, compared to a fixed production rig, which may spend decades at one location producing hydrocarbons from an oil or gas field.

A set of parameters that affect the importance of spare parts have been set up to explain the need for spare parts, with a basis on drill rigs and their complications with being moved from one location to another. The usage rates of which parts are used, replaced or maintained play an important role and needs extensive monitoring and analysis to have a good estimate of the expected life time of a given component, part or system. Rules, regulations and criticality of equipment affect the safety of the drill rig, personnel and the environment. There need to be detailed analyses and planning of consequences, safety systems and the availability of such critical parts. Storing and transport of spare parts to offshore drill rigs will have affect on the logistics for spare parts.

Offshore drill rigs has limited storage space and weight limitations that need to be taken into consideration when deciding which spare parts are to be located on the rig, and which can be stored at onshore facilities. The concept of moving the rig after a relatively short period complicates the process of having equipment stored and establishing means of transportation. Simplified, the parts that are considered highly critical to safety, required by governmental and other regulations and parts that are essential to avoid downtime should be kept available at the rig. Such parts can be replaced with only a few hours of downtime and possibly even without stopping the operations. Less critical parts are kept at onshore storage facilities or ordered from manufacturers based on the timeframe to be available offshore. To complicate the planning of spare parts further, many parts have an unpredictable demand, some parts will become unavailable, new manufacturers and brands are introduced and delivery times may vary from the stated values. In addition to part or system history, analyses of usage rates and modeling there are recommendations from manufacturers to aid creating a system for controlling spare parts.

Finally costs will always be an important factor in decision making. The costs of having a drill rig wait for several days and the consequences of a serious accident while drilling are of such magnitude that expensive equipment, advanced monitoring, redundant systems and other safety measures may often be worthwhile. Because of the large numbers of different parts on a drill rig, the spare parts are categorized into high, medium and low criticality groups, where computerized programs and modeling has great potentials in simplifying the logistics and reducing costly over- and under stocking. Such computerized program should involves as many as possible factors and set of data available to establish a good model for the need for

spare parts. The system needs to provide simple and understandable data, with possibilities for both offshore and onshore personnel to update, control and gain information on current stock, deliveries, part history and other relevant statistics.

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1. Introduction to spare parts in offshore drilling operations

The motivation for studying spare parts for drill rigs is primarily to find a way of determining the most effective number of spare parts to keep available and consider where to store the spare parts. Spare part logistics are more complex for offshore operations than for an industrial plant onshore regarding several factors like transport, storage, installation, downtime costs, maintenance and the possible consequences of failures. Among the offshore installations the drill rigs involve some problems that are not found on most other rigs due to the fact that a drill rig is not a stationary installation, but it will be relocating when drilling operations are completed. An installation put up to handle production for an oilfield will often be in its place for periods up to 20-30 years, while drill rigs often are on a contract for 2-5 years at a time. Setting up logistics for a drill rig will have to be a more short term task, since the rig may be moved in a short time frame resulting in changes in transport, storage locations and local conditions.

The main goal is to identify the most important parameters and their effect on spare parts logistics for drill rigs. The parameters will be evaluated based on their criticality and effect for the drilling companies in form of downtime, safety and logistics. In addition to the spare part parameters there will be a brief study of industry methods of planning and executing spare parts handling for offshore drill rigs.

The number of spare parts is determined from results of analyses of parameters that indicate the importance of these parameters. Each parameter is to be described and assessed based on its influence and possible consequences if ignored. The criticality and importance in each parameter is to be implemented in the model and its effect to the total number of a certain part will be reflected from this prioritization.

The results of having an effective spare part system is reduced costs, higher level of safety and possibly more efficient operations at offshore drilling. Such improvements can help to reduce costs and profitability of drilling projects, especially at remote areas and limited reservoirs where the profitable margins are scarce and logistics difficult.

The problem to be address in this thesis is, as previously mentioned, to identify and evaluate a set of parameters to determine the need for spare parts for drill rigs. With emphasis on problems specific for drill rigs study these parameters and their effect on spare part logistics.

As a practical study a drilling company operating in the North Sea will be reviewed with regards to handling of spare parts. A description of a computerized tool for maintenance and spare part handling will be made and linked to the use of the mentioned parameters to determine the need, use and problems with spare parts for drill rigs.

1.1. Spare parts for offshore drill rigs

There is a lot of equipment, personnel and money involved in the whole operations of offshore drilling. This involves not only the operator controlling the drilling operation, but the entire system that makes such operations possible. The operations are planned and executed over several years with large investments from operating companies, service providing companies and investors. Still the drilling operations, where a drill rig normally is hired to an operating company for a given time frame, will normally last for 2-5 years with possibilities for extensions of contracts. After the operations are finished, the drill rig is removed and taken to the next location for drilling, either to drill another well or it may be taken on a new contract for a new operator. Operating this way involves relatively short working periods at each location and includes operation in various environments, with its strain on the rig and equipment being used.

When drilling offshore there are many components that may fail during operations, advanced technology is pushed hard to perform its best in harsh environments where a failure can have severe consequences, not only economically, but to personnel and environment. To minimize downtime from unplanned events like equipment failure and missing parts there is a need for replacement parts ready to be installed when needed. In addition to having spare parts available, there is a need for a plan in how, when and where to make repairs, upgrades and storing equipment.

Moving the rig around could make changes in the logistics of spare parts for each new location. How far the rig can be moved without changing the logistical system around spare parts varies with several parameters. Some locations may have similar conditions regarding aspects from weather and environment to the physical challenges in drilling a well in search for hydrocarbons. Other environments may have extensive changes when regarding weather, available infrastructure, physical drilling conditions and with respect to safety and criticality measures.

1.2. Equipment failures

Wear and tear are normal processes that affect all moving components, normally in a degrading way. Drilling operations are especially exposed with demanding environments, hard working conditions and challenging logistics with operations. The obvious is the drill bit getting worn out by cutting and crushing the rock formations, but the wear is more complex. There are bearings and moving parts with long term exposure to temperature changes, shock and different chemical substances. Lubrication, seals and gaskets will degrade even with protective seals and careful monitoring; resulting in wear to equipment and finally failures if not replaced. If such failed equipment is not replaced the operations will often need to be stopped, while costs are running. Improved technology and research have made equipment and tools more reliable and longer lasting, but there will always be a tradeoff between costs and durability. When such failures occur, there have to be a system to replace the failed component and bring the system back to working condition. Such systems vary within components and systems, but basically they consist of either replacing a component at a timed schedule or when replacement become necessary through indications as failures, reduced performance and other abnormalities. Such solutions are expensive and time consuming, but the alternative of having to shut down operations is a less favorable option.

1.3. Financial aspects

There is put extensive amounts of time and money into development of technology and advanced equipment to last as long as possible to make equipment more robust and reliable, but still wear and tear of equipment working in harsh conditions will be impossible to fully design out. Because equipment is damaged and worn out there is a need to change the parts, ideally before they fail. Through maintenance, monitoring and experience there are possibilities to extend the working time of components and predict how long they will last. Still with advanced monitoring and technology there will be unforeseen failures and equipment will break down from misuse, mistakes and unforeseen events. Such maintenance and monitoring has its costs, but the costs associated with a failure and the following downtime may be even more considerable. Even with the high costs for advanced technology and costs for running the rigs, the rewards still make the effort in offshore drilling worth the costs.

1.4. Problems

Spare parts are as mentioned essential for effective operations, especially at considerable distance from equipment manufacturers and supplies. For a drill rig the distance from manufacturer or spare part storage locations are more complicated than for stationary production rigs, because drill rigs are moved between locations as they finish one project and head on to the next one. Bringing the spare parts on the drill rig and keep them available at all time is unfortunately not a realistic option, for offshore drill rigs space is a limitation and one cannot offer room for all desirable spare parts. This is a major challenge in keeping the downtime as low as possible for offshore drill rigs, since extra equipment in most cases need to be transported offshore when needed.

When planning spare parts and trying to obtain an ideal number will often result in either overstocking or under stocking of spare parts. Unused spare parts will result in unnecessary costs, especially if they degrade over time and new parts will have to be bought for future projects. Too few spare parts on the other hand may have more severe consequences, such as violations of regulations, downtime and possibly an increased risk, for both personnel and environment, if a failure should occur.

Fluctuating demand is a problem associated with spare parts where the usage rate for parts is hard to predict. For these situations there may be little help in average use of parts or statistical life time of a component. In addition there may be major uncertainties in both usage rate and reliability in equipment and components resulting in difficulties in predicting a reasonable number of spare parts.

Transporting the spare parts offer some special challenges for drill rigs. Because of the relatively short timeframes at each location, there are challenges in transportation logistics at a more frequent basis than for a long term, well established transportation agreement. At various locations the availability of nearby warehouses, equipment and the time needed to transport the equipment impose new challenges.

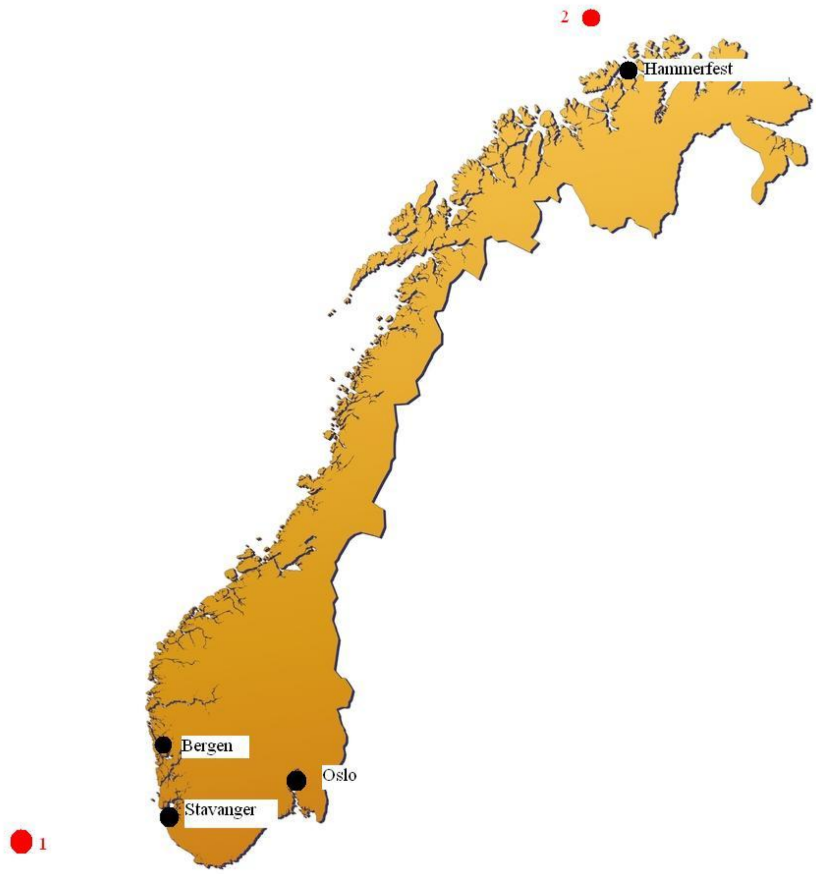

Figure 1: Different locations of a drill rig

A map can illustrate the problem with a drill rig being moved from location 1, where it has completed its drilling operations, to location 2 for its next project. The figure, its locations and distances are for illustrational purpose that having a well established spare part system and warehouse facility at one location may need to be changed when the drill rig is moved to a new location. The distances and logistics of such relocations are of varying scale and complexity. The distance a rig is moved may vary with large distances and deciding on whether the spare part logistics needs to be changed, improved or optimized is an assessment based on several factors. in some cases the storage facilities and means of transportation can be kept the same, with little or no impact on the availability of the spare parts, while other cases require extensive restructuring of the entire spare parts system.

In this example the parts are manufactured in Oslo, and then moved to a warehouse outside Stavanger to be available to the drill rig working in the North Sea at location 1. After completing the drilling operations the rig is moved to outside Hammerfest for new drilling operations there, at location 2. The spare parts system which involved Manufacturing in Oslo and storage in Stavanger will become considerably more complicated and time consuming regarding the transportation process from storage facility to the rig. The criticality, cost, usage rate and several other parameters involving the availability of spare parts should be evaluated and considered when possibly designing a new spare part system.

1.5. Advantages

Avoiding waiting time for a replacement for a failed component will often be the main purpose of keeping a spare part. From this inconvenience in waiting, one can evaluate how much effort and resources there are reasonable to invest in avoiding the waiting time. For offshore operations the waiting time can prove costly and lack of certain parts may prove a serious hazard to safety measures. The costs of downtime is especially considerable for drill rigs since they are run on a hourly basis with costs running, even when there is no work being done.

From a safety perspective there are great advantages in having spare parts and redundant systems for critical components and systems. A drill rig involves hazardous situations to both personnel and environment if equipment and parts fail. Such accidents are not only damaging people, environment and the rig itself, but the responsible companies will receive fines and penalties.

1.6. Choosing parameters

To make the spare part system as efficient and cost effective as possible there is a need to establish a set of parameters to identify the need for spare parts available to drill rigs during operation offshore. To keep the spare parts at a favorable level, the parameters need to consider the number of each part that gives the most cost effective result. At the same time they need to offer an acceptable safety factor and act within rules and regulations for offshore drilling operations. The different parameters will have to be prioritized by their desired effect in affecting the number of spare parts. Some parameters are functioning as minimum requirements, while others will contribute in increasing the number of spare parts above set minimum levels. In addition to number of parts, for drill rigs especially, there should be an evaluation on where to keep the spare parts, since the rig is likely to be operating at different locations and storage space on the rig itself is very limited.

When choosing such parameters one needs to estimate and evaluate the need for spare parts and make some sort of system to determine their criticality and necessity. The parameters need to take into consideration the criticality of the function of each failure. The costs and drawbacks from a failed component will indicate its necessity to a back-up system. From that there will be different needs to repair, change or replace the part to put the system back into working condition. Some parts and components will in other words need to be covered by redundancy and spare parts readily available, while other parts are ordered and delivered when needed.

2. Methodology

Studying spare parts for drill rigs is an ongoing process which will not have a definite answer and solution. There are however solutions to improve logistics, reduce costs and simplify operations, while still have focus on health, safety and environment.

The literature in this thesis is based on articles, publications and compendiums in spare parts management and a survey of the usage of spare parts in offshore drilling operations based on a drill rig company operating in the North Sea. Some set of parameters are identified to determine the need and importance for spare parts and their criticality to operations. The parameters have been evaluated based on information from research articles and practical experience from various projects where Apply Sørco is involved.

Articles and publications from various sources regarding fields like maintenance, condition monitoring, logistics and spare parts handing have been studied and related to the usage of spare parts for drill rigs. Information regarding maintenance, drilling industry and reliability is available and their application to spare parts has been studied. Information regarding importance and criticality of spare parts is available from a wide range of industrial settings, both published papers, articles and the web pages of organizations performing such research.

Information directly related to decision making when it comes to spare parts for drill rigs and the identification of need of keeping such parts available have been scarce. The process of planning the use and availability of spare parts, the system related to the spare parts and the logistics around location of such spare parts have been more difficult to gain direct and detailed information to. Industry standards and their processes are not normally published in detail for everyone to read and study. That is why Apply Sørco in Stavanger have been contacted and included in the process of writing this thesis. The information provided by Apply Sørco has been valuable to get insight to industrial application and work processes for spare parts of the oil and gas industry. Especially the possibility to gain understanding of real life industry processes and way of thinking has become valuable information and experience to write this thesis.

Most of the information regarding drilling operations and the way of linking spare part theory with drilling operations has been based on information provided by senior engineers and project managers in Apply Sørco. The theory behind spare parts are listed in the bibliography, but the information of how drilling operations are using spare parts comes from conversations with disciplinary leaders and senior project leaders in Apply Sørco during the period spent at the office location at Forus, Norway.

As a practical example of how spare parts are planned for and operations are executed there have been interviews with key personnel to the handling of spare parts for several drill rigs operating in the North Sea. There are no specific details in equipment, rigs or programs, but a description of the computerized systems that is at its final stage of development before being put to use.

Information regarding the companies, programs and personnel involved will not be described in detail due to legal concerns and the use of the system.

3. Identifying the most important parameters for evaluating the need for spare parts in offshore drilling

There are numbers of parameters affecting the need for spare parts in offshore drilling. In this chapter the parameters considered to be the most important have been studied based on findings from literature and information provided from Apply Sørco.

3.1. Rules and regulations effect on spare parts

When drilling offshore there are risks involved in the operation. Both environmental, economical and risks concerning the safety of the people involved in the process. To control these risks and keep them as low as possible and avoid serious damage to personnel, infrastructure and environment there are rules, regulations and recommendations issued by the government and organizations like the Norwegian Petroleum Safety Authority. These regulations should be followed and adapted to, to avoid fines and possibly stopped production. The reasons for such regulations are the principles of Health, Safety and Environment, HSE. When evaluating number of spare parts, the goal should be keeping the operations as safe as possible and avoiding accidents caused by lacking spare parts.

The petroleum Safety Authority has a set of regulations relating to conducting petroleum activities. In these regulations, chapter 9 defines need for maintenance and spare parts. “Section 46 Classification” (Petroleumstilsynet(b), 2011) states that:

Facilities' systems and equipment shall be classified as regards the health, safety and environment consequences of potential functional failures.

For functional failures that can lead to serious consequences, the responsible party shall identify the various fault modes with associated failure causes and failure mechanisms, and predict the probability of failure for the individual fault mode.

The classification shall be used as a basis in choosing maintenance activities and maintenance frequencies, in prioritising between different maintenance activities and in evaluating the need for spare parts.

For spare parts at operating drill rigs there are regulations concerning safety of the mentioned personnel, infrastructure and environment. The NORSOK D-010N (Norsok(b), 1998) is an example of such a set of recommendations intended to keep drilling operations as safe and environmentally friendly as possible. The NORSOK D-010N for drilling and well interventions describes that critical spare parts or back-up equipment with a long expected delivery time should be identified and possibly be placed either at the platform where it is to be used or at a land based warehouse. The evaluation in where to keep the parts is to be considered based on the criticality and the consequences of a failure and how to perform the repairs or improvements.

From a spare part point of view these regulations are made to ensure there is plan or solution available to problems involving examples like the need for spare parts as the biggest challenge. Critical operations and safety systems like fire extinguishing mechanisms, gas detection and alarm systems are areas where regulations are to ensure safety is kept at a satisfactorily level (Norsok(a), 2001). The NORSOK has several other standards involving the decisions made when evaluating spare parts, where the criticality analysis together with maintenance and reliability are important factors.

An example of governmental involvement in spare parts planning with focus on HSE is the work Petroleum Safety Authority Norway (Ptil) did at Nyhamna, the land based plant for the Ormen Lange field. Ptil investigated the plant with regard to large scale accidents and maintenance. The regulations of June 17th 2005 nr 672 and regulation FOR2003-12-19 nr 1595 and the follow-up of the regulations made (Petroleumstilsynet(a), 2011). As a result there were no direct violations to the regulations, but the availability of spare parts for high criticality equipment was recommended to be improved.

The equipment used for drilling offshore is being classified with respect to the consequence of a failure or fault and the time it takes to install a spare part are determined by the generic maintenance concepts.

The regulations regarding safety and high criticality operations from government and safety authorities like Ptil have to be followed as a minimum, even in some cases where proven economically impractical. If component reliability, downtime etc indicates that the number of spare parts should be higher than what is stipulated by regulations one may implement such solutions.

The approach to spare parts from a rules and regulations point of view is to minimize risks for all parts involved through a thoroughly and detailed maintenance and inventory plan. Key performance indicators are to be monitored during the work processes. Equipment specific regulations such as OEM requirements and internal requirements are recommended to be followed to maintain expected performance, reliability and life time. Potential functional failures are to be identified with their probability of associated fault modes, failure causes and failure mechanisms.

When all the mentioned factors are analyzed and evaluated with a satisfactorily result, then the operation, with regards to spare parts, are within the rules and regulations for the need of spare parts.

3.2. Criticality and reliability of equipment

3.2.1. Criticality analysis

Criticality of an asset can be identified as the importance to the business or the risk posed to the company if the asset fails based on the consequence of such failure. From a spare part point of view a highly critical component that fails must be replaced, by either a repaired component or a new component, as fast as possible (Huiskonen, 2001).

Some components are more important for safety than other, such components need to be identified and failure modes analyzed. Such an analysis should prioritize the components criticality and the need for spare parts based on consequence of failure. Depending on the components they should be categorized into levels of criticality with a specific estimate for the need of spare parts and their availability (Patton Jr. & Feldmann, 1997) (Huiskonen, 2001).

The first risk to assess is threat to personnel working on and around the rig (Patton Jr. & Feldmann, 1997). There is great potential for injuries and death associated with failures of offshore drill rigs, as leaks of highly flammable and explosive petroleum fluids may ignite. In addition to fire and explosions there are a number of hazards associated with offshore drilling and weather conditions that may make the situation even worse. Very important systems may require a fully independent system to take its place upon a failure, since one cannot risk having the system out of work even for shorter repairing intervals (Patton Jr. & Feldmann, 1997).

Damage to the environment is another risk that should be avoided to stay within governmental regulations and showing good company ethics (Patton Jr. & Feldmann, 1997). Components essential to avoid emissions and detect such failures are of high criticality since the consequences may have such damaging effects. A bad environmental reputation may also affect the company financially.

Damage to infrastructure may result in economic loss for both operators and other companies working on and around the rig (Patton Jr. & Feldmann, 1997). Equipment may be damaged and production may be delayed for considerable time with its associated costs.

The risk from a operations point of view is the possibility for a stop in operations, both short and lasting downtime may lead to serious economic losses. Even if there is no real threat to personnel or the environment, this is a serious economic threat that will increase with the amount of downtime, since drill rigs have high operating costs, a costly working crew and tight timeframes.

There will rarely be serious accidents or failures only leading to one of the consequences. If there is a large explosion at an offshore drill rig, there is reason to believe that there will be some kind of combination of damage to personnel, infrastructure and environment as the platform itself is damaged and finally a stop in production due to evacuations and repairs.

The potential for harm to personnel, the rig and the environment together with the potential for lost production makes the criticality assessment of equipment an important factor when considering number of spare parts. Parts with large consequences of failure need appropriate spare part and back-up equipment solutions available at all times, ready to be installed within a given time frame (Patton Jr. & Feldmann, 1997). Other parts that may minimize such consequences should be considered if appropriate and within reasonable probability.

Decreasing both the probability for a catastrophic accident offshore and the time it will take to stop such an event is of great interest.

Defining and assessing the failures and risks involved is a difficult task that need thorough understanding of the mechanisms involved. There are many unknown factors like probability of different events to happen, reliability and consequences of such an event. To establish estimates of such parameters involves, among others, analyzing previous events, expert experience and computer modeling.

3.2.2. Redundancy

The reliability of a component or a system is an important part of the criticality evaluation. The consequences and its associated probabilities are all affected by reliability or unreliability. It is common to simplify the reliability measure by probability models describing the probability for that a component will behave in a specific way. Like that the number and frequency of failures are normally distributed with the expected lifetime around the mean.

There will always be uncertainties in models and outcomes of failures. A given part may have an expected lifetime with an estimated or measured standard deviation. Still there will always be a given probability that the component may fail right after installation or last longer than anticipated.

For systems with a need for high reliability and simple measures to bring the system back into working condition there are solutions with complete redundant systems. This consists of a similar system as the exposed one that may take care of the failed systems tasks with no, or only minimal stops. The redundant system need to be installed and ready to take over the same workload without change of parts and relocation of components. With a complete redundant system for the most critical systems, both the combined reliability will be increased and the probability for a not functioning system will be decreased.

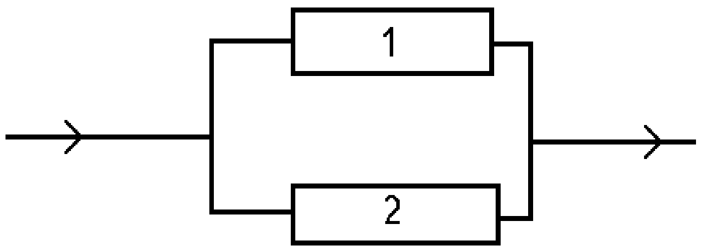

Figure 2: Redundancy

The figure shows a simplified example of a redundant system. Where component 1 can handle 100% of the demand and component 2 is an identical component available to be brought to use if component 1 fails. The principle is used for many purposes ranging from valves, pumps and electric circuits.

For a drill rig operating at different locations at relatively short time frames reliability of essential equipment and processes is very important. Because of the changing conditions and locations of the rig there are great advantage in having an as reliable as possible overview of important functions to properly plan for spare parts. With a high reliability, there is less need for overstocking in case of unforeseen events.

3.2.3. Risk acceptance

Setting numbers on approved limits for what probabilities, expected fatalities and operational downtime is a difficult task. Total elimination of all risk will never be possible, there will always be a given probability for one or several essential components to fail, personnel to make mistakes and unforeseen incidents to happen.

Setting a number on the probabilities is an assessment where principles such as risk aversion, consequence analysis and risk acceptation should be evaluated. All operations will as explained involve some kind of risk and minimizing this risk has its costs. That involves in most cases a financial question, but also logistical challenges. There will be great differences from each situation and facility. If the risks are too large to initiate the project, measures need to be taken or operations should be abandoned.

In short terms, if the added cost of necessary safety improvements makes the total costs of the project greater than the outcome of the project, then the project should be terminated. On the contrary, if the improved reliability or increased safety is within given frames of costs, then this is a necessary improvement that should be implemented to the project (Metso, 2010).

Evaluating the accepted risk is an evaluation to make individually for each project and the individual consequences. For a drill rig, as mentioned previously, the basis for such an evaluation may different risk acceptance criteria at different locations. An established system may only be appropriate for the area it has been designed for. When the drill rig is moved to the next location, the risk evaluation from previous areas may be of little interest.

A principle known as ALARP, As Low As Reasonably Possible, involves such evaluation where there always will be risks involved, but which are possible to minimize to a point where further reduction is unreasonable, based on practical application such as costs, technology and operating conditions.

When the operations involve a risk for fatalities, the principle FAR, fatality accident rate may be used. The FAR principle describes the expected number of fatalities in 100 million exposed hours. Still there is a need to decide on how many fatalities one is willing to accept.

Damage to assets and lost income from downtime is easier to put numbers on and to evaluate objectively what makes sense and what involves financial problems. Still there are the same difficulties in determining probabilities and categorizing what may happen and what outcome such an event might have.

Environmental damage can have a determined expected cost involving fines and downtime, but also like damage to personnel has consequences that are difficult to determine. Reputation and popularity are factors, which will be implicated from an accident, that are hard to predict the outcome of.

3.3. Identifying the usage rate

3.3.1. Technology

Since exploration drilling started around the 1960s in the North Sea there have been extensive technological development in technical equipment and the way it is being used (Oljedirektoratet, 2011). The natural start for this type of thinking is a system based on "run to failure" principles being upgraded to have some kind of indication of problems. With this indication comes an action to prevent such a failure, either a plan for repairing, spare parts or a combination of the two. There is available technology for monitoring ranging from simple detector to advanced computerized systems for entire plants (Mobley K. , 1990).

The development in technology with regards to spare parts involves some important factors. An important factor is the way equipment and installations have been modularized. From the start of, failed equipment and functions would be repaired, involving many spare parts and extensive operations in repairing such equipment. The development is headed in a more modularized direction, where a failed function results in removal and installation of a new component. An example is a failed pump; this pump may have a failed bearing, seal or electrical problem. Instead of repairing the pump at the drill rig, a back-up pump is installed and the failed pump is sent back to onshore facilities for repairs, modifications or disposal. Other examples may be modules containing advanced technology or other components consisting of a series of separate parts working together.

There are however costs associated with installing, maintaining and operating these systems; the more complex the system will often mean more costs. As technology will continue to develop, there will be more solutions and more advanced systems, but as the technology become more available, the price and complexity may decrease (Huiskonen, 2001). There is a consideration for all operators and industrial companies to decide how advanced and sophisticated technology that is cost effective and justifies the implementation costs and the work associated with operating the system. This concept will be the same for spare parts, as technological components will have longer expected life time, become more effective, more available and easier to produce. As modularization is being further developed, changing parts will become faster and require less manpower, equipment and time. Availability of interchangeable modules or components will increase and further contribute to easy installation and repairs.

3.3.2. Condition monitoring and management

When determining spare parts one needs to start with the decision of whether to replace the failed part with a new one or by a repaired one. This concept is known as defining the spare parts into either “repairable” or “replaceable” (Mobley K. , 1990). This involves having either a set of new parts ready to be installed or a number of parts running a cycle between being repaired and being used. Repairing worn out parts will involve the mean time to repair; MTTR, concept with two parameters, how long time is a repaired component expected to work and how long will it take to bring a broken component back into the system (Mobley K. , 1990). The expected time the component will be running is dependent on the:

- Quality of the part
- Environment it is being used in
- How hard the component is being used
- What kind of work the component is used for

The time it will take to bring a failed component located on an offshore drill rig back into use will depend on the transportation from the rig to the workshop or repair location, the actual time it takes to repair the item, the transport time back to the rig making it ready to be installed back to the working location. For critical functions, this method of having the system out of working condition, is unsatisfactorily and needs a better alternative. There needs to be either a back-up system to take over the failed systems workload or the failed system needs to be brought back to working condition within a given time frame.

For most components the expected working time is an estimate based on statistics, manufacturer calculations and other measures which all include an estimate of reliability. In other words there is a certain probability for that the newly installed spare part may fail before it is expected to. The criticality of this reliability has to be considered when deciding on number of spare parts. How reliable the system needs to be and how large probability of “no available” spare part that can be accepted is dependent on the part and the criticality of the system involved.

How many spare parts that are needed will be determined from several parameters like the rate of repair and the rate of failure, combined with the usage rate. This consideration will depend on many factors, like the components reparability, reliability, criticality and failure rate. Condition monitoring may contribute to improve the evaluation of need for spare parts by giving an indicator of the physical condition of potentially failing equipment (Mobley K. , 1990). If a condition monitoring analysis indicates that given components are close to failure, these components may be included in an upcoming repair or upgrading interval.

Depending on their condition, value and criticality, equipment may be set into groups like capital, operational and consumables.

3.3.3. Maintenance

All industrial operations will to some degree involve use of mechanical systems and physical components that will to varying degree need maintenance. There are three main categories:

Preventive, corrective and replacement maintenance to prevent future failures through repairing, modifying or replacing components, systems or parts that are likely to fail within a set timeframe or operating period (Mobley K. , 1990).

A large part of the maintenance will be planned and scheduled maintenance with minimal part changes, like change of lubrication and filters (Mobley K. , 1990). Even if lubrication and filters are changed at a schedule there will be wear and tear of all moving parts in mechanical equipment especially. Some parts will due to wear and long term destructive usage need to be changed with a new part, a spare part. Ideally this change is foreseen and planned at the most convenient time, thus avoiding production stop at the most busy time of year and machine failure during critical operations (Mobley K. , 1990).

When to change a part or piece of equipment at an offshore drill rig will rarely have one definite answer. There will in most cases be several factors to consider when determining further action. Some components may only need change of wear parts, other have a distinctive lifetime with some degree of reliability and possibility to predict. From a spare part oriented point of view there will be either keeping the complete part in stock or having the exposed parts ready for repairs and replacements. Common for both is that there is an advantage to be able to predict when a failure will occur. This type of condition monitoring will make operators able to plan for, make judgments and take action to a failing component. Each component will have its associated course of action, from limited preventive maintenance to complete change of the worn component.

There are three main categories when looking at when to change a component, where each has its associated advantages and disadvantages. The principles of “Run to failure”, “Preventive maintenance” and “Predictive maintenance” are central when considering the need for spare parts and what maintenance approach that should be selected (Mobley K. , 1990).

Modifications, repairs and other measures that need the production or operations to be stopped are planned to be executed at convenient times. In such a way it is possible to have several repairs and modifications going on at the same time and by that limit the number of required downtime periods and use the inactive recourses like manpower during the downtime (Huiskonen, 2001).

3.3.4. Run to failure (from compendium)

Run to failure is as the name indicates that a component, as a complete machine or physical component is used until it stops working sufficiently. The idea is based on the concept of that something that is not broken, should not be repaired (Mobley K. , 1990). Initially the company does not have to spend any money on repairs and monitoring of the equipment condition, which contributes to keeping costs low. For complex industrial organizations and plants like an offshore drill rig this method will often end up as the least cost effective method because of the extensive work that needs to be done when something fails, breaks or need repairs.

Since there is no monitoring, there is no way of predicting when a failure will occur or what parts it may involve.

This method is rarely used in a true "run to failure" principle, since there will often be types of preventive measures like change of lubrication and minor adjustments (Mobley K. , 1990). The expenses associated with this type of maintenance become evident when parts or machinery fails and need to be replaced or repaired. There are considerable costs to downtime when drilling offshore. If a major component breaks down it needs to be repaired immediately to keep the rig costs as low as possible. Since there is no monitoring one might assume that several components will fail simultaneously since damaged parts can affect the rest of the machinery. One example is damage from vibration and wear due to insufficient lubrication which will affect several components in a machine with moving components. To make the downtime as short as possible one need to keep an extensive amount of spare part in stock and a repair crew ready at all times. Another option is relying on parts from manufacturers when needed, but considering transport offshore at inconvenient hours and the delivery time the costs might favor keeping spare parts.

For offshore drill rigs, this principle is only possible for low criticality functions, where replacement or redundant solutions are available and an unforeseen failure will have little or no implications on either production or safety. Items of low criticality which involve no real threat in failing may be used in a run to failure principle.

3.3.5. Preventive maintenance

An alternative to running the components and machinery until they fail is to take action to prevent the machinery from failing and thereby cause downtime to the rig. Common to these preventive measures to avoid failure is that they are time driven, either as hours of operation or elapsed time since last service, modification or repair (Mobley K. , 1990). To make good assumptions upon how long a given component can run there is a need for experience and statistical data to calculate the expected hours of operation or life time of the component. Then there should be chosen an interval between failures, where the probability for a failure is adequately small. This interval is known as the Mean Time Between Failure, MTBF. Other common abbreviations are the Mean Time To Failure, MTTF, which is the average time a component will work until it is time to replace it. Mean Time To Repair, MTTR, is the time from a component has failed until it is finished repaired and ready for use (Mobley K. , 1990).

The criticality of the component, including consequences of failure and the problems associated with replacing the component at an inconvenient time should be considered when choosing the maintenance interval. Choosing a small interval makes failures less likely, but the maintenance costs may be unnecessary high. On the contrary, choosing a too long interval will increase the probability of an unplanned and unscheduled failure, bringing the same disadvantages as with the run-to-failure approach. The use of the components or machinery can have an effect on when a failure will occur. A component is more likely to fail during hard usage, like maximum strain or working capacity.

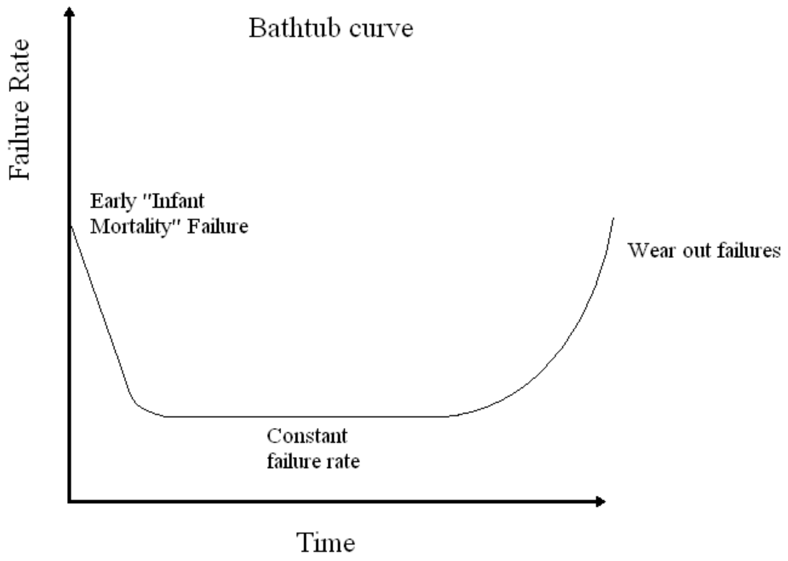

Figure 3: Bathtub curve (Mobley K. , 1990)

For many mechanical components the principle of the bathtub curve will apply to their failure rate over their intended lifetime. The model indicates that there will be a high failure rate in the beginning of the operation. The high numbers in the beginning are based on installation problems during the initial phase and other failures associated with getting the system into operations. After a time the failure rate will stay relatively low and constant during the lifetime of the component. At the end of the life time of the component the failure rate will start increasing. The rates and duration of each phase will be specific to each part, but in most cases mechanical components will follow such a curve. For spare parts this can be used to plan for number of parts in specific periods of the life time of a component and when to change the part, order new ones or in some cases expect it to fail within a short timeframe (Mobley K. , 1990).

3.3.6. Predictive maintenance

Even for relatively similar components there may be large differences in degradation, especially if there is a varied usage load and possibly lack of statistical data on the expected lifetime. To be able to foresee future problems based on more indicators than earlier experience one needs to monitor the condition of the component (Mobley K. , 1990). There are several ways of monitoring the condition of a component, including vibration, infrared imaging and output performance. Common for all condition monitoring measure are to detect abnormalities in the work cycle of the component being monitored. These abnormalities, like vibration, should be assessed and evaluated. At a certain level the system should be stopped and the component creating the abnormal conditions should be repaired or replaced by a spare part. By constantly monitoring one may be able to predict when a repair or replacement is necessary and prepare for the needed repairs. This way one will be able to avoid many of the problems associated with unplanned maintenance such as stop in production at most inconvenient times and costly special deliveries of spare parts. Especially for the vibration example there is a possibility to stop the vibration before serious damage is made to expensive equipment. This because normal mechanical failure mode degrades at a speed directly proportional to their severity, indicating that repairs at an early stage is of great importance (Mobley K. , 1990). Generally predictive maintenance is classified into five major non-destructive techniques:

3.3.6.1. Vibration monitoring

Mechanical and especially rotating equipment will often involve vibration monitoring as the main predictive maintenance indicator. This principle use two basic facts, all “common failure modes have distinct vibration frequency components can be isolated and identified” and “the amplitude of each distinct vibration component will remain constant unless there is a change in the operating dynamics of the machine-train” (Mobley K. , 1990).

3.3.6.2. Process parameter monitoring

As for vibration monitoring, evaluating the output from a system can give good indications that the system is not operating under ideal conditions. Where such indications combined with further analysis and testing can reveal upcoming failures and indicate a need for maintenance (Mobley K. , 1990).

3.3.6.3. Thermography

Thermography is the technique of monitoring emitted infrared radiation, heat, from a source to identify its condition. The technology is based on the fact that all physical matter will emit energy when temperature if above absolute zero temperature, -273, 15 degree Celsius (Mobley K. , 1990). When determining the need for spare parts, one may use thermo graphic monitoring to identify areas that are warmer than the normal value, and increase in temperature in a bearing over time will be an indication that the friction in the bearing have increased. There are available instrument ranging from simple spot detectors to advanced scanning microprocessor based imaging systems.

3.3.6.4. Tribology

Tribology refers to design and operating dynamics of the bearing-lubrication-rotor support structure of machinery (Mobley K. , 1990). There are several techniques used to predict failures in parts involving both analyzing the lubrication and wear particles from the machinery in the lubrication fluid. The analysis of the lubrication fluid can be used to determine if there is a need for more lubrication fluid or if the fluid needs to be changed due to physical and chemical degradation. Primary applications for lubrication oil analysis are quality control, reduction of lubricating oil inventories and determining the most cost-effective interval for oil change. The particles found in the lubrication will often come from the machinery itself and thereby indicate wear which is tearing the machine down. With improved technology and advanced microprocessor-based systems it is possible to analyze the fluid sample effectively and precisely determine the content and its source.

3.3.6.5. Visual inspection

Visual inspection of equipment can in most cases help determining the need for maintenance and spare parts. Critical parts are studied routinely by experienced operators and abnormalities are recorded. Advantages are that the technique is fast, simple and in most cases cheap to perform resulting in that this technique should be added to the list of preventive maintenance (Mobley K. , 1990).

3.3.7. Benefits with predicting, preventing and avoiding failures

There are a number of benefits associated with having indications of failures before they will happen. As explained previously some of the most common advantages of predicting, preventing and avoiding failures can be summed up as: (Mobley K. , 1990)

- Lower maintenance costs
- Fewer machine failures
- Less repair downtime
- Reduced inventory
- Longer machine life
- Increased production
- Improved operator safety
- Verification of condition
- Verification of repairs
- Overall profitability

These aspects make the usage rate of components an important parameter when considering the need for spare parts at an offshore drill rig. There are large costs involved with large volumes of spare parts, advanced monitoring systems and the consequences of downtime in drilling offshore.

When dealing with spare parts, this type of monitoring can help avoiding downtime in a number of ways. All of the mentioned monitoring methods can be used to detect abnormalities in operation conditions. When such abnormalities are detected one may either change the worn part or start planning, ordering and getting ready for changing the part, dependent on the criticality and consequence of the indicated failure.

The expected lifetime of the component is a critical measure when determining the number of spare parts to keep in stock for an offshore drill rig. Unpredictable components are obviously more important to keep in stock as they tend to fail more often than the reliable long lasting components. Components with short lifetimes and little indication of an upcoming failure will have less room for error in logistics and delivery when needed. Such components need extra considerations in where to be stored and increased stock could be evaluated if it will prove reasonable.

3.4. Spare part storage

3.4.1. Location

When considering spare part logistics for an offshore drill rig the questions about where to keep the parts, how to make the repairs and who to do the job become evident problems that need to be planned and executed to function properly.

There are several factors to consider when deciding where to store spare parts for industrial machines and equipment. The first consideration should be if there is room for storing the part close to where it is needed. Offshore could be a problem, especially if the spare part is large and heavy since there normally is very little storage room and weight limitations to spare. An offshore installation is an example of where extra room is scarce and missing a crucial component will lead to large costs. If there is no room for the component at the plant, one needs to decide where to store it and how to move it when there is a need for the part or component.

Many drilling operators have storage facilities where equipment like spare parts can be stored at onshore warehouses and ports. For this to be an alternative, the spare parts need to be movable to a certain degree. If it takes more time to move the part from the storage facility then to order a new part from the manufacturer, then of course ordering a new part when needed is a better alternative. The criticality of the component is of course also a factor to take into consideration when choosing storage location. A component that does not need to be changed within a short timeframe could in many cases be stored at a storage facility. On the other hand, if the part needs to be changed within a short period of time, the part has to be close to where it is to be installed.

Experience and studies shows that overstocking is a common industrial problem. This is a problem that does not become evident right away and will not produce clear problems. In the long run these parts lead to unnecessary economical expenses that often could have been avoided with a better spare part management system. A lot of spare parts are stored at warehouses and without maintenance or proper protection they will be useless after a given time period (Berger, 2004) (Huiskonen, 2001).

As explained above, the decision in where to store spare parts is not a simple question with one clear answer. There are many logistical and practical considerations to make the use of spare parts simple and efficient, with as little lost productive time as possible. Each factory, plant or business needs to make its own considerations and priorities when deciding where to store spare parts and if spare parts should be stored or simply bought when needed. The delivery time, storage price and quality are some of the factors that will be individual to the given company or organization.

Combining the problems above with that a drill rig is moved to new locations at a frequent basis the logistics with spare parts will have to be assessed and determined at a frequent basis to keep operations efficient and profitable.

3.4.2. Spare part pooling

Many spare parts are not used at a frequent basis. That may sometimes make it possible to have one spare part for several machines, if they most certainly do not break down at the same time. If then the machines are located at different divisions a new choice of where to store the part needs to be made. If there is not enough room to store the part at either of the plants or machine locations, then like before, the part needs to be stored at some storage facility. If there is room at the plant, then it may be difficult to choose where to store the spare part if there are no obvious locations that needs the part the most or is most likely to fail first. Another solution may be if there are a storage facility located somewhere near all of the facilities, making the spare parts and the rest of the equipment available for all divisions. Which is a common solution for industrial land based facilities like factories, for offshore use this solution may be applicable for storing spare parts at onshore warehouses. An example could be to have spare parts located in a warehouse near Stavanger to supply several drill rigs in the North Sea. When a drill rig has completed its operations at a given location and is moved to a new location the logistics with spare parts needs to be revised. In some cases the distance the platform is moved is short and making it possible to use the same storage facilities. If the platform is moved for a great distance, it will be necessary to arrange with new storage facilities and transportation logistics.

3.4.3. Degradation during storage

Another possible problem with storing spare parts over time is the degradation of the component. The degradation is very dependent on the storing conditions and the material the part is made of. The conditions at offshore installations in the North Sea are not ideal for storing equipment. Humid, salty conditions with variable temperature and possibly exposure to direct sunlight is of course bad for most materials and contribute to increased material degradation like corrosion over time. While dry, at a stable temperature inside a warehouse is in most cases good storing conditions. This will contribute to the importance of keeping a correct number of spare parts on site and replacement may become necessary for rarely used parts (Patton Jr. & Feldmann, 1997).

Depending on the actual component, some spare parts should not be stored over long time intervals. One example is fast developing technology like computer hardware and advanced machines. If the spare parts are not used often, then when they actually are needed, they may be outdated and not usable. This is extreme cases, but if the timeframe for the component is very short, then it may be a better alternative to buy new parts when they are needed. This will also apply to storage at onshore warehouses, but such storage facilities will often supply several rigs and industrial plants. It is of course not much sense in keeping a warehouse full of non usable spare parts.

3.4.3.1. Maintenance on unused stock parts

If there are spare parts on stock, both unused ones and repaired old parts, then after some time in an offshore environment they may need maintenance to be in proper working condition.

Tools for changing spare parts at offshore drill rigs have to be available for the repair to be made. There are considerations to be made, like with the parts, whether to store the tools offshore or at onshore warehouse locations. If spare parts are kept offshore and ready to be installed, then the same should be for the tools, to avoid unnecessary delay.

If spare parts are to be transported from onshore warehouses or manufacturing facilities, then there are more factors to take into consideration with the tools. It will be simple and effective to keep the tools located at the rig, ready for when the equipment arrives, but as previously explained, room is scarce and unnecessary weight is a problem.

3.4.3.2. Who to make the repairs

Drilling equipment consists of complex and advanced technology and may sometimes need for specialized personnel to change and install spare parts when old ones are worn out. The equipment manufacturer will often also offer spare parts as a part of their service. This will make need for a choice of which solution to choose. If the repair crew can offer parts at a reasonable cost, then that solution will often be favorable for the company or machine owner.

When looking at the offshore installation example as mentioned before, there may often be of great advantage to train and educate offshore personnel in repairing and maintaining the equipment used offshore. If there is a repair operation or a part that needs to be changed within a short timeframe this will help getting the operations up and running faster than if a repair crew is to be sent from an onshore location. On the other hand, if the spare parts that are needed are stored onshore because of lack of storage space, then the repair crew could just as easily be sent offshore in the same time as the spare parts.

3.4.3.3. Specialized equipment for the repairs

To perform repairs and modifications on advanced technological equipment there will in some cases be a need for specialized tools and measuring devices. Such equipment is often expensive and rarely used. The personnel operating the tools and devices need to have experience and knowledge to perform the repair and measures. There are several possibilities to handle the specialized tools and equipment for offshore repairs and modifications. The same reasons apply to the equipment as the repair personnel, but for the equipment storage at the rig is a possibility. Limitations are of course the same as for the spare parts itself with limited space, degradation and costs.

A lot of the standard tools being used will in most cases be at the offshore installation and need to be so if both spare parts and repair personnel is on site. If specialized repair crews are being transported to the rig, there are more possibilities for bringing equipment along as long as transportation logistics and timeframes allow this solution.

3.5. OEM recommendations and warranty

With many tools and components there will follow a set of recommendations for operations from the manufacturer which needs to be followed to be covered by their product warranty and to obtain expected life times, reliability and performance. Some components may have a guaranteed lifetime, when operated as intended, like service intervals and maximum load or stress. Within these limits the component may have a high reliability regarding both performance and safety.

Most products will have some sort of safety margin in their stated lifetime and performance, but the manufacturer recommendation will in many cases be a good baseline for operations. The manufacturers are in most cases the most experienced operators of their own equipment and have an extensive testing and approval process before releasing a new product.

For some parts and components the recommended service or replacement interval can be followed with desirable results like that unforeseen failures are reduced to a minimum and performance is as intended. Critical parts will still need a given amount of parts as backup, since the lifetimes and reliability stated by the manufacturer will always have some probability for error within the expected operating interval and lifetime.

If these recommendations are not followed the manufacturer of the equipment will not replace the component within the warranty interval and there may be other financial difficulties in the event of a failure.

Evaluated against governmental rules and regulations, criticality analyzes and costs the recommendations from manufacturers can contribute to handling and planning of spare parts and avoiding failures and unscheduled downtime.

As a drill rig is being used at several locations, with frequent changes, there may be different considerations from manufacturers. Some components may be developed for working conditions such as tempered climate, moderate water depth etc, while drill rigs may move from drilling in tempered climate to ultra deep water drilling in the Barents Sea with unpredictable and extreme weather. This adds up as another challenge with a drill rig compared to a fixed production installation, where future operating conditions are simpler to predict.

3.6. Costs with spare parts

Too many spare parts that end up unused and taking up space may lead to unnecessary costs, while too few spare parts may lead to critical situations resulting in damage to personnel and equipment with lost production and hence larger costs. There are costs involved in both repairing worn out parts and the alternative of ordering new parts when old ones are worn out. The transport and storage costs are involved in both situations, but there will be a difference in buying a new part and repairing an old one. The most cost appropriate method will depend on the spare part that needs to be replaced and its reparability and complexity. There will still be costs with either repairing or ordering a new part, thus the concepts will be treated the same way when looking into acquisition and holding costs (Huiskonen, 2001) (Patton Jr. & Feldmann, 1997) (Kärkkäinen & Småros, 2009).

Drill rigs involve large costs, often on a daily basis, resulting in that downtime will result in increased costs, while avoiding downtime may have considerable costs involved too. Adding that the rig will be moved from one location to the next complicates the cost estimates since costs of transport, storage and part specific costs may change from one location to another.

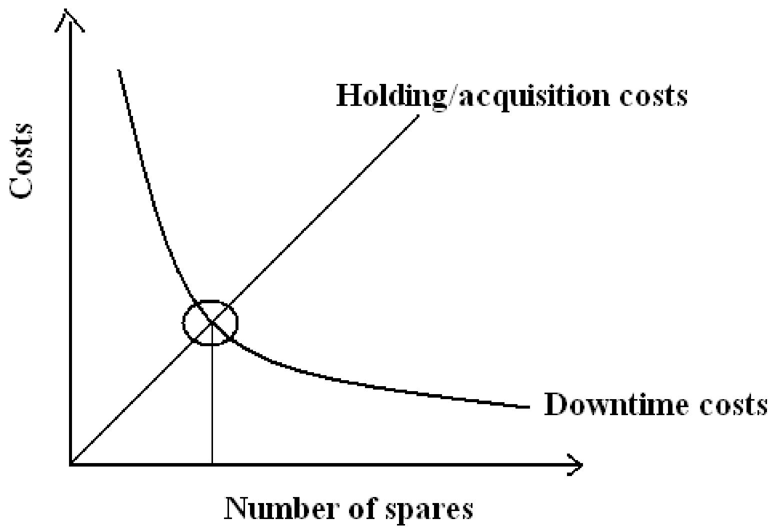

Figure 4: Costs

3.6.1. Overstocking spare parts

Keeping spare parts available at drill rigs at all time involves costs in many ways. The spare parts must be bought, the acquisition costs, they need to be transported to location and there may be costs involved in storing them at the offshore rig. There are costs associated with not having spare parts ready for use when needed. Drill rigs are expensive to run, both renting the rig, paying the workers and other costs make downtime an expensive result to lack of spare parts. There are differences in the criticality of the spare parts, they may break down in different rates and other complications will make the decision of how many spare parts to keep difficult. With a varied offer of spare parts for all possible failures ready for installation one may be able to keep the productive downtime to a minimum. Having a spare part for every part on the plant is at best difficult, but most realistically impossible in a real situation. There are both economically and logistically reason for not keeping spare parts for every possible failure, as explained earlier (Berger, 2004).

The sketch shows how increased amount of spare parts is plotted against total costs with the lines indicating holding/acquisition costs and downtime costs. Since the total costs are a result of both costs of the spare parts and the costs of downtime, one needs to find some middle course to keep costs as low as possible, but still within earlier established parameters like rules and regulations, criticality measures etc. The intersection of the lines may be a possible number of spare parts by using this model, this is where the combined downtime costs and holding/acquisition costs are at its lowest.

3.6.1.1. Acquisition costs

There may in some cases be advantages in buying large number of parts and transporting large quantities at the same time gives less transportation costs, but possibly more complex handling. Especially parts that are small, light weight and with a high usage rate might have these advantages. For spare parts with fluctuating demand and long periods with little or no consumption, the trouble with handling, storage and logistics may outweigh the advantage in procurement costs.

The type of spare parts will affect the costs, some parts will be impossible to store large quantities at the same time, e.g. large and heavy. While other parts are more optimal to keep larger quantities in warehouses and storage facilities, like low cost items with high usage rate.

The prices for buying, transporting and handling individual parts are higher than comparing the same part in a planned operation of buying complete systems. The extra costs in logistics around the single or low number of parts makes costs in all phases larger. This adds up in disadvantages associated with acquisition costs of dealing with spare parts (Huiskonen, 2001).

3.6.1.2. Holding costs

The costs associated with holding of spare parts may be complex combinations of several factors. The costs with having available parts offshore may affect the model both ways, but storing equipment offshore will have many factors increasing the costs. If storage space is limited, there will be costly redesigning and constructing in making space or expanding storage space just to make it possible to have the spare parts located offshore (Huiskonen, 2001).

If parts are stored, especially if stored offshore, there will be costs associated with maintaining the condition of the spare parts in its original condition. The storage space may in also need configuring and upgrades to protect from harsh environments, such as saltwater, sunlight and temperature changes.

All the mentioned costs will contribute to the costs associated with having spare parts store at offshore locations or rig sites. The more parts necessary, the more the costs will increase, the same for the time the parts are expected to be stored before use.

3.6.2. Insufficient number of spare parts

Keeping large stock of spare parts are as explained expensive, but keeping too few spare parts may have severe consequences to both safety and costs of operations for the rig.

The costs of such a situation where vital processes stop will in many cases be extensive. If a critical component in operations is missing, the processes will stop and lead to no work being done, while rig costs still are running.

3.6.2.1. Downtime costs

Because of the costs associated with running an offshore drill rig are extensive and especially the costs of having a drill rig operative make downtime an expensive operation. When missing essential parts makes drilling or operations stop for longer periods, the rental costs for the rig and personnel will still be running. In addition there might be a tight time schedule for some operations, such as installation of rigs and modules where the operations are very weather dependant. Even small delays may contribute to large costs and lost productive time. Such spare parts should be given extra considerations if keeping extra parts may contribute to avoiding downtime.

3.6.2.2. Damage to personnel, environment and equipment
From a safety critical point of view, missing a component may involve even larger consequences than the downtime costs. Accidents may cause serious damage to personnel, environment and infrastructure, with its corresponding costs.

3.6.2.3. Fines and delays
In addition to damage to production, personnel, environment and equipment from accidents, failures in keeping safety critical components within established rules and regulations may result in fines and other penalties, even if the accident has not occurred. The responsible part may then have to repair, upgrade and get the situation approved before operations can be brought back to normal conditions.

3.6.3. Spare part classification / ABC classification
Spare parts are normally put into classification to simplify logistics. One method is using the classes A,B and C where spare parts are categorized after their value and amount available (Huiskonen, 2001).

Class A spare parts represent only between 10-15% of the total number of inventory items. These few parts are high cost parts, which in monetary value represent between 70-85% of the total invested value of inventory. (Markeset(b), 2010)

Class B spare parts represents between 20-30% of the total number of inventory items. These parts are middle range cost items with in monetary value represent about 25% of the inventory value. (Markeset(b), 2010)

Class C spare parts are the typical frequently used and simple items with low value even for large number of items. Class C represents 60-70% of the total number of inventory items, but only about 10% of the total inventory value. (Markeset(b), 2010)

3.7. Transportation and infrastructure

3.7.1. Transport
When transporting equipment offshore there are more factors and limitations involved than transport of goods on land. The spare parts are either stored at an onshore warehouse or ordered directly from the manufacturer. After storage or manufacturing the parts need to be prepared for shipping and transported to a nearby dock and made ready for the ship to transport them offshore. Then both loading and offloading needs to be done by crane or some other type of lifting devices, especially offshore where the height of the rig makes offloading more difficult. Some transports from onshore facilities to oilfields offshore needs special weather considerations. Transportation of spare parts may be considerably delayed due to changes in weather conditions offshore. With high waves and strong wind it is impossible for

ships to sail and even worse for cranes to lift equipment from the ship to the rig deck. Transporting large modules, such as when a platform is built offshore is especially weather dependant, but this will also apply for smaller spare parts. The problems with weather can to some degree be planned for, by making the most weather dependant transports in periods of the year with less wind and rough seas.

The ships have great storage capabilities both in size and weight, making this way of transportation effective, especially for the North Sea. The disadvantage with ships may be the speed they can transport equipment, making well established infrastructure onshore close to the oil fields being produced. For newly developed fields in remote areas the transport time with ship may be considerable and departures may be less frequent.

Heavy equipment is transported offshore on ships and lifted to the platform deck with cranes, for smaller objects and personnel there are helicopters flying from onshore locations to the rigs offshore. The helicopters are very limited with capacity to weight and size, in addition to being expensive, but faster than ships. This makes helicopters more applicable for transportation of personnel to offshore facilities and between such facilities. With helicopter landing areas both on platforms and many of the ships being offshore this way of transportation is very useful, but still limited by weight, size and weather conditions.

3.7.2. Available infrastructure

For an offshore drill rig there are many challenges with spare part delivery that are not necessary to account for when working onshore and close to equipment manufacturers. Transporting equipment will at best be more difficult, but may also be delayed because of weather changes, shipping difficulties and other problems.

If spare parts are to be delivered from onshore facilities the infrastructure available will be essential to transportation times and costs. Both if spare parts are to be transported offshore when needed or stored offshore they need to be transported from manufacturing facilities to offshore installations. If there is available infrastructure close to the offshore installations the transport will be simpler, faster and more economical.

Most spare parts are manufactured at factories at different locations, then transported to docks, warehouses and storage facilities or transported offshore. If there is a well functioning infrastructure for this the time and costs will be lower than for more complex situations.

A transportation system of spare parts to a stationary platform will not involve many changes during several years compared to a drill rig, which will be at each location often for only a few years before it is moved to a new location. This move complicates transport and available infrastructure for drill rigs, as there may not be available warehouses and transportation logistics onshore near the new operating location.

When considering number of spare parts, the infrastructure and transport considerations will contribute to the acceptable number of spare parts. This because of lacking infrastructure and expensive and complicated transportation might favor keeping more spare parts than previously assumed. With a complicated transport and lacking infrastructure there are a greater probability for delivery delays and unforeseen costs when ordering spare parts and transporting them offshore. Difficult transportation conditions, either because of infrastructure, weather conditions or distance from shore will affect the decision of how many spare parts there is a need for, especially critical equipment sensitive to delays.

3.8. Availability from manufacturer

Spare parts for an offshore drill rig are a part of the planning phase when designing and constructing the rig. There is a significant timeframe from design to the point where the rig has been operating for a given time and needs spare parts. After a given time there will most likely have been improvements and changes in the equipment being used. The completed rig is designed to be operating over considerable periods of time, over this lifetime there will be improvements, changes and technological advances in industry standard.

An offshore drill rig consists of many components with a varied expected life time and new components are replaced with new alternatives as technology improves. When planning spare parts for a drill rig, it is important to make sure the spare parts that are to be used are available at all times, especially for critical components.

The availability of spare parts from manufacturer will be especially important for systems which are replacing failed parts with new parts directly from manufacturing. If there is an unforeseen failure at an inconvenient time and the failed component is no longer available there may be considerable downtime. Such scenarios are possible to avoid either by keeping a minimum number of spare parts available or paying attentions to changes in technology and industry standards. Then there will in most cases be possible to upgrade or change components and parts of systems to be compatible with the new standards.

3.8.1. Upgrading the system as the industry evolves

After a period of time without failures, upgrades or modifications, the technology available may have advanced and the older components may no longer be in production. They may have been replaced by a new set of components and the old components may no longer be available. When considering spare parts, this needs to be implemented in the plan to avoid having problems finding a spare part and avoid major changes in layout at inconvenient times, when there is a need to quickly replace a worn part with a new one. Downtime because of repairs and modifications of complete systems will in such cases be time consuming and expensive and such major modifications would better be done at more convenient times, as planned maintenance periods.

As technology advances and old solutions become incompatible with the new components, the system may have to be upgraded or modifications need to be made to enable new spare parts to be used. In addition there are often other advantages when new systems are developed such as improved performance, increased reliability and better monitoring capabilities. Improved performance, increased reliability and better monitoring will, amongst other advantages, contribute to the decision in upgrading the current system to new solutions and current technology.

Upgrading a system to be compatible with new components may become a costly modification. This depends on the complexity and details of the actual system. For systems with long life time and great importance, the advantage of a new compatible system may outweigh the investment in recourses and time to make the upgrades and modifications.

3.8.2. Keeping old parts in stock

Keeping a large stock of old units is an option, to avoid being in a situation where one need spare parts that are no longer in production, but it is an option with many disadvantages. To some degree this is possible, ensuring that there are spare parts available until the system is changed or upgraded, but in the long run the solution with many old parts is not very effective.

Even if the disadvantages and problems earlier explained with keeping large spare part stocks at offshore installations, the stock will eventually run out and the problem with outdated systems and incompatible new parts is inevitable. When this situation occurs it may be impossible to get spare parts and upgrading the system is inevitable. In addition such a situation is likely to be at an inconvenient time, because such an event will be when a component has failed. The costs of upgrading at this time will in many cases involve considerably more costs than if the upgrades were done at a more convenient time. Like during times of little activity and scheduled maintenance is occurring. At this time it may be possible to have available personnel, tools and parts to make the upgrades fast and effective.

3.9. Changing demand for spare parts

3.9.1. The demand for spare parts

The demand for spare parts is often very hard to predict and specific and accurate estimates are hard to obtain or calculate. The need will vary with both the specific part and the conditions it is to be operated in. Some parts may have predictable life times and follow the same statistical rate for long periods. Which makes the service intervals relatively simple to plan for and only a minimum of back-up equipment may be needed at all times (Kärkkäinen & Småros, 2009).

The problem with spare parts with less predictable life times is how many spare parts to keep available at all time. Some parts may have long expected life times, but still be very unreliable when predicting life time. There may be an expected life time of several years, but only at best an estimate of its reliability and probability for failure before the expected life time.

Spare parts will have a different demand, depending on several factors. Some components are more likely to fail for reasons like area of application, design and expected life time. The demand for a given part may vary in seasons, but also in a more random pattern.

3.9.2. Prediction models

The problem with making a model for unpredictable demand is that there will rarely be reliable data to base the model upon. In addition to the lack of data, such demand often contains demand peaks, followed by an unpredictable period of time with little or no demand. This makes an average life time calculation of little interest and use (Kärkkäinen & Småros, 2009).

There are models made to help predict the demand for spare parts at given industrial settings. Some models are made especially for dealing with sporadic and irregular demand, one example is Crostons method (Kärkkäinen & Småros, 2009). For a long time industry used exponential smoothing and average numbers as models to predict demand, with results leading to unsuitable inventory levels. In 1972 Croston proposed a model which takes account for size of the demand and inter-arrival time between demands. The model gives more appropriate numbers for sporadic demand than both of average and exponential smoothing. The model has been used with modifications, within the industry, since it was made in 1972 (Kärkkäinen & Småros, 2009).

To create a prediction model, one needs thorough information about the equipment and components which failures are to be in the model. Data on failure frequency, life cycles and probabilities together with real statistical observations are of great value. Obtaining such data is both time and resource consuming, resulting in that for most cases these data will only be profitable for expensive and high criticality components.

Even with prediction models and expensive data collecting actions the reliability of these models will be poor. Resulting in that for most situations there will be an attempt to make reasonable and realistic estimate of spare parts needed, based on limited data.

3.9.3. Dealing with fluctuating demand

For critical parts, which always have to be available, there may be periods where the parts are unused for long intervals and others where there is a constant need for ordering of new spares or repairs of used ones. To make the task worse, some parts may have zero demand for long periods and irregularly have extensive demand for spare parts. Because of unpredictable demand there will be necessary to either have an accurate model or overstock essential spare parts (Kärkkäinen & Småros, 2009).

For inexpensive and easily stored components this will mean overstocking at convenient locations, with relatively small extra costs. For critical and important components without a proper model, the only solution will be overstocking with its associated disadvantages (Kärkkäinen & Småros, 2009) (Berger, 2004).

4. Evaluating the parameters

The parameters described in chapter 3 will in this chapter be evaluated based on their implication on offshore drilling. Based on their effect and consequence if ignored, the parameters will be prioritized and classified.

4.1. Evaluating the importance of the parameters for a moving drill rig

4.1.1. Rules and regulations

Rules and regulations is an essential parameter when considering number of spare parts. The rules and regulations are evaluated on a safety point of view by government, independent groups and agencies. If such values are violated the consequences may vary from fines, shut down until improved or accidents to happen. Examples like NORSOK standards are not regarded as rules, but more as guidelines and recommendations, they are however based on well documented findings and a good recommendation.

When dealing with offshore drilling, especially in harsh and exposes environment this parameter needs to be taken seriously and the regulations from local governments and controlling agencies are to be followed. The alternative is abandoning the project or redesigning to make the project within the rules and regulations. This parameter may change as the drill rig is moved to the next location, which enforces the operators to keep track of local variations. There are different rules from governments and environmental considerations may be different at various locations.

Some locations are considered more delicate and easier affected by drilling operations than other. In addition the emergency logistics have different challenges in dealing with oil spills, damage to personnel and emissions from one location to another. Examples are the North Sea with extensive onshore infrastructure, supply vessels and rescue services compared to newly explored fields in the Barents Sea, with little or no onshore infrastructure near the field.

4.1.2. Criticality

Having an effective spare part system may have considerable advantages for a drill rig when it comes to safety and repairing important systems. There are logistical problems involved in the fact that the rig will be located in one spot over relatively short periods and with varying distances to travel to the next location.

The criticality parameter reflects upon the consequences of keeping the wrong number of spare parts. When considering number of spare parts one may simplify the situation as too few parts, sufficient and too many parts. Ideally one should keep exactly the number needed, but uncertainty in demand and predictions make that a difficult task.

Keeping too many spare parts available is not a problem regarding the criticality and reliability of equipment. On the contrary this situation is desirable when only considering this parameter, but parameters like costs, storage, transport and several others involves complications with overstocking of spare parts.

From a criticality point of view the real threat is the lack of essential and safety critical spare parts. The consequences of keeping too few spare parts may have catastrophic consequences both economically and to infrastructure, personnel and environment.

These results make the criticality measure a very important parameter when considering number of spare parts. This parameter evaluates and prioritizes each spare part from its consequence of failure, with regards to damage to personnel, infrastructure, equipment and environment as possible outcomes from a critical situation with lack of spare parts to be installed when needed.

4.1.3. Usage rate

The rate of which parts need to be replaced with either new ones or repaired ones on a cycle is important for considering how many spare parts to have available or on cycle, where to keep them and how to plan the operations regarding change of spare parts. These factors show that the usage rate needs considerable attention when designing and considering number of spare parts. The consequences of faulty priorities may be downtime in production, exposed facilities, environment and personnel if safety critical equipment is not available.

The usage rate for spare parts may have some differences when a drill rig at a given location is moved to another. Still the main challenge is the availability of parts, where a high usage rate may make the situation even worse. Some parts usage rate may be directly affected by the local conditions of where the drill rigs are located. Factors like weather conditions and formations to drill in will affect the rate of which drilling equipment is worn and from that make an impact to the need for spare parts. When planning the spare parts logistics for such a drill rig that will be at one place for relatively short periods before moving needs to take into consideration the various locations this rig may end up at.

The impact of which the usage rate of parts and components may have on running a drill rig makes the usage rate an important parameter when considering the number of spare parts that are needed.

4.1.4. Spare part storage

The way of dealing with spare parts is another factor that needs planning and correct execution. This parameter involves essential logistics of keeping the spare parts that are considered necessary to keep available. For a drill rig the ideal scenario would be having all possible spare parts easily available and ready for installation. This is however not an option and most spare parts need to be stored at warehouses and onshore facilities, if they are not ordered from the manufacturer when needed or in a repair loop. The storage parameters are affected when the rig is relocated in that there might be a need for relocating the spare parts to another storing facility closer to the operating area.

For a drill rig working in the North Sea, many of the spare parts will be located at convenient facilities in places like Stavanger, which is close to where the rig is and with transportation available. If the rig is moved to remote locations, like the Barents Sea, the spare parts might have to be moved as well to a location closer to the rig. This will depend on the time frame that is given by the importance of the actual spare part. If the necessary delivery time for a part is several weeks, the costs of relocating the spare parts may result in that parts are ordered when needed.

When having spare parts at storage facilities it will be important to monitor the inventory level and keeping it up to date. Dependent on the importance or criticality of the spare part there will be a maximum and a minimum level of parts to be located at the storage facilities. Keeping too many spare parts will, as explained, lead to increased costs, while too few may have even more severe consequences. This is why the number on stock needs to be between the maximum and minimum number of spare parts. When parts are sent offshore, the inventory level needs to be controlled and if the inventory level is below the reorder level, new spare parts needs to be ordered to keep the inventory at a sufficient level.

4.1.5. OEM recommendations

The recommendations from original equipment manufacturers can be used as a baseline for what a component, system or part is intended to endure and perform. Exposing such an item to conditions outside its intended working limitations will often affect performance, reliability and lifetime. Some components may have some sort of guarantee for its performance, but that will only be applicable if the working conditions have been within set limits.

When considering spare parts for a drill rig, such recommendations are of interest when planning the maintenance schedule. The information provided by OEM will, like other information, have a degree of reliability with unknown factors involved, but still this information is valuable and a good indicator of how to operate the equipment.

Staying within OEM recommendations has clearly its advantages, but some may speculate in using components longer than their intended life time and with harder workloads to save money in buying new components or maintaining old ones.

The recommendations from original equipment manufacturers is a parameter that require little research and effort to obtain and in most cases comes with the purchased equipment. Planning spare parts for a drill rig cannot be purely based on numbers given by the manufacturers of the equipment, but where little research has been done and information is scarce this is an important parameter to consider. If there are factors like warranty and refunds for failed equipment, there might be worth the effort to put some considerations to the OEM recommendations.

4.1.6. Costs

The costs of having a certain number of spare parts will always be a factor to consider, since operations ideally should be as profitable as possible. Keeping spare parts available for a drill rig may involve large costs with both having the parts available and having new parts delivered to the rig. Not only the costs with buying the parts, but transporting possibly heavy equipment over large distances and off shore have its costs.

For a drill rig that is moving at frequent basis, the costs get more complex and demanding. For a stationary rig that is to operate at the same locating for 10-20 years, there will become well established transportation routes and logistics will be simpler. For a drill rig, there will be necessary to establish such an arrangement when the rig has finished the drilling at a given location and is moved to the next. In some cases the rig will only be moved a short distance, there will be costs involved with each such arrangement.

The alternative to having expenses with spare parts and their logistical difficulties is having unplanned downtime when important components fail. Because of the high rates of having a drill rig operative, the costs with downtime will in most cases far overweigh the costs with having a spare part network ready to ship parts that are necessary.

The costs with spare parts are important when considering number of parts to keep available, especially for marginal projects. Still the costs associated with having the drill rig out of working order for long periods will in many cases encourage overstocking of spare parts. The ideal situation with no need for spare parts is not likely to happen, but with high reliability on equipment, maintenance programs and condition monitoring of especially important and exposed components one may avoid many failures. Based on logistical possibilities and costs there will be spare parts available at different locations for a drill rig.

4.1.7. Transport and infrastructure

Transporting spare parts involves challenges, when the rig is frequently relocated the challenges are even more extensive. The transport and logistics around the transporting process is an important parameter when designing a spare part system for a drill rig. The transportation logistics with spare parts for a stationary rig, like a production rig, that is to be at one location for 10-20 years will only require some work at the start of the project and possibly some improvements as experience shows betters solutions are available. A drill rig will need spare parts to be available within short time frames and possibly at new areas with little infrastructure available onshore, at a frequently changing basis.

The difficulties and importance of effective transportation of spare parts will make this parameter important to consider when determining the number of spare parts at different locations. The number of spare parts that are necessary will in the case of transport be dependent on the time it takes to have a new or repaired part delivered at the offshore installation. There is a need for more spare parts than what other parameters indicate if there are long delivery times with considerable uncertainties with the delivery of the part.

4.1.8. Availability

The availability of spare parts is an important parameter for considerations of how many spare parts to have available for a drill rig. This parameter has the same implications on number of spare parts as the transportation parameter. If there are spare parts available onshore, close to the rig, the operator of the drill rig may be able to have the spare parts transported offshore when needed. When drilling operations are completed at the current location and the rig is moved to the next location, this system of spare part delivery is changed. The distance where no changes in availability vary with several considerations in the ability to move the spare part, time needed to move the spare parts and the costs of doing so.

The problems associated with availability of spare parts from manufacturers will have many of the same implications for a drill rig as for a stationary rig. Choosing types and number of spare parts based on the reliability and knowledge that the components will be available for the intended lifetime of which it is to be used is important, but not a specific problem only for a drill rig. Avoiding and designing out solutions, that are likely to be without spare parts and difficult to repair after a given time, will more or less eliminate the problems with the availability parameter. Solutions with a well developed maintenance program and spare part logistics is also in most cases a better option for simple and reliable repairs and avoiding downtime.

If the future availability of spare parts is underestimated there may come a situation where a relatively simple, but important spare part is unavailable. Many parts will have similar components that are applicable, but if such a solution is not available, there will be a need to make further changes and rebuilds to equipment and operations.

4.1.9. Changing demand for spare parts

Dealing with a fluctuating demand brings challenges, when the demand is changing frequently; there are more considerations to be made. Determining the number of spare parts is difficult and unreliability is involved. The demand will have some additional factors that may be independent from one location to another, making this parameter even more important for a drill rig as for stationary rigs. Some locations and environments will wear out parts faster than other, some parts are not appropriate to be used in some conditions, while others may perform unexpectedly well in some conditions.

The system that is set up to deal with a demand that is fluctuating at an unpredictable way, needs to be adapted to new conditions when such changes are appropriate. For a drill rig with short operating times at each location this means that the system needs to be easily changed and adaptable to a number of factors. The consequences of not having an efficient model when the demand for spare parts are fluctuating and conditions are constantly changing will result in either increased logistics and costs from overstocking and possibly costs associated with lack of spare parts. As explained previously there are different levels of criticality among the spare parts and that each should be evaluated with their consequence of not being replaced or repaired like planned for.

4.2. Prioritizing

Prioritizing parameters for determining the number of spare parts will not have one definite answer since different situations require different prioritizing. For a drill rig that is on contract with an operating company with expected result within a given time the main concern is completing the well and moving on to the next project and location. The operation needs to be within given standards like quality, time and regulations. Such regulations may control the allowed emissions to sea and air and other pollutions caused by the drilling operations.

The different parameters will all have their consequences if there are violated or ignored. The highest level of parameters will be the ones resulting in a complete stop in production, where repairs, upgrades or reengineering needs to be done before operations may start again.

The first step in prioritizing the parameters is, as explained, to identify the highest level, which will be the parameters that, if violated, will stop the entire operation with a high probability. Either through not fulfilling local rules and regulations or involves too much risk for large costs, injuries and death. In addition there will be costs associated with violation of such parameters in form of fines and operational downtime. High priority parameters need to act as a baseline for other parameters. Such high priority parameters will indicate the lowest number or level of spare parts and the longest allowable time from failure to the system is back in working condition. Further parameters may build upon the high priority parameters and further increase the stock of spare part and possible indicate even shorter time frames for installation.

Middle level parameters are those, if violated, which will lead to large problems and with a high probability cause operational stop for shorter periods. For a drill rig, such measures result in downtime, lost income and increased costs.

Lower level parameters will result in inconveniences and possibly operational stops. Such events may result in increased costs, based on the effects from not following the result from analyzing the parameter.

Based on the evaluation of the parameters in this thesis, there will in this example of a model be three priority classes for the parameters. Such parameters may have different priorities at special situations and conditions. Such priorities need to be assessed at local conditions, with the consequences and risks that are applicable for such a situation. An example of classification of parameters for a given location, situation and drill rig is explained:

4.2.1. Level 1 parameters

The highest prioritized parameters are considered to be Rules and regulations, Criticality and Usage rate. The Rules and regulations need to be prioritized to enable the operations to run without getting stopped or rejected from given areas and projects. It is common with organizations to observe hazardous operations and interfere in operations if the situation is regarded as hazardous to people or the environment. If such operations are detected the operations will be stopped and analyzed further, with financial losses for those involved. If the analysis reveals violations to the regulations the responsible may receive fines and be forced to improve the conditions.

The criticality parameter involves the safety of the personnel working on and around the rig, the exposure of the rig and the safety of the environment, both around the rig and within possible affected distance.

At last the Usage rate parameter will consider the rate equipment will be worn out and need repairs, maintenance, change of parts and replacement. If this parameter is ignored there is likely to be situations where the rig will be brought to a stop while waiting for equipment, parts and repairs. Scheduling downtime and repairs for several components and foreseeing wear, failures and faulty equipment has as explained previously great advantages.

Common of these three parameters are that if ignored the activities intended with the rig will, with a high probability, be stopped. Either as forced stops from ruling agencies, governments etc, accidents and incidents that could have become accidents or simply the lack of needed parts, components and other equipment

4.2.2. Level 2 parameters

The level 2 parameters are considered to be Costs, Transportation and Storage because if violated, ignored and overseen these parameters may cause downtime and most likely include increased costs. When planning spare parts there are costs involved in most parts. As explained in the cost parameters, one will have to limit costs where applicable without seriously affecting efficiency and safety. Ideally all spare parts should be kept next to where it is to be used, for offshore drilling this is not a possible situation and some kind of compromise between what is wanted and what is reasonable must be made.

Transportation of spare parts from storage facilities or manufacturers to drilling rigs can affect the drilling operations with extensive delays, making this another important parameter. This parameter is also highly affected when the drill rig is moved to another location. If the transportation of spare parts is not planned and properly executed there will be increased risk for costly downtime in operations.

Storage of spare parts will have the same effect as transportation. The spare parts that are to be used need to be at a convenient location and ready to be installed when needed. They need to be in working condition and compatible with the equipment offshore they are to be used with. Like for transportation, the storage parameter may, if ignored or violated, result in either lack of spare parts, delayed delivery and delivery of degraded spare parts upon a situation of failed components. With the common result of high probability for increased downtime, these parameters increase costs and the time it will take to complete operations.

4.2.3. Level 3 parameters

The level 3 criticality parameters are interpreted as not likely to cause extensive consequences, but may cause the operations to be less effective and may increase downtime. Original equipment manufacturer recommendations, Availability and Changing demand are in this example regarded as low criticality. These parameters can be avoided by following the higher prioritized parameters, but should still be evaluated for overseen situations.

Original equipment manufacturer recommendations can be used to help determine the need for spare parts, but because of local changes and conditions there will often be of greater use to make an analysis for the actual working conditions of the equipment and parts. This parameter could have a higher priority in some situations where warranty and other original equipment manufacturer advantages may influence the prioritization.

Availability of spare parts for the intended usage period is another parameter that needs to be handled, but in most cases can be dealt with. Especially for drill rigs where contracts involve relatively short timeframes. If the equipment is made by the principle of modules, where each component can be changed with a new one, there are good flexibility in modifying and repairing equipment.

Changing demand for spare parts needs to be planned for and possibly modify the need from usage rate to have enough spare parts for periods of more than average need for certain parts. The consequences for not foreseeing a fluctuating and unpredictable demand may be that some periods there will be overstocking of spare parts, while other periods may suffer with lack of spare parts at locations like storage facilities. For the drill rig the overstocking is not an issue, but lack of spare parts at the storage facilities and warehouses may result in downtime while spare parts are brought in from other locations or manufactured.

4.2.4. Classification

The classification of the parameters is not a definite answer; priorities, equipment specific details, local conditions and other factors may influence the prioritization in both directions. There will however always be some parameters prioritized over another and thus making a bigger influence on number of spare parts decisions. Such high criticality parameters will often involve extensive consequences if they are ignored or violated. Such consequences may range from lost income, fines and damage to personnel, infrastructure and environment making these parameters very important to take into consideration.

For a drill rig that is relocated at a relatively frequent basis, not only the numbers of spare parts indicated by the parameter, but also the importance of each parameter may change from one location to another.

5. Industrial example

As a verification of the thesis several conversations with senior engineers and project leaders who has insight to the logistics for spare parts for a rig company operating in the North Sea has been made. The information obtained through several conversations has provided knowledge of the basics in spare parts management the offshore drilling industry. The latest contribution to handling of spare parts is a computerized system to combine and link several sources of spare part data in one common program, which is intended to simplify the logistics with spare parts. The system described is an ongoing process which is expected to come to use spring 2011.

Categorization based on criticality is used to make the handling and planning of spare parts simpler, but still there are large numbers of spare parts that needs to be kept track of. Such information is stored in several sets of data, models and computer programs. A common problem is information and updating between onshore and offshore personnel and the number of computerized databases. The offshore personnel has the best understanding and overview of the condition of equipment, maintenance needs and the need for spare parts, but access to inventory information, data on tag specific items and the history of equipment is not as available. A tag is in such a setting, briefly explained, a number to identify a specific item, part or component as a part of a larger system. Onshore personnel have such information, but may lack the current information of status offshore, especially combining sets of data from several sources. Contacting offshore personnel to check tags, types and conditions of each component is a time consuming process. When different manufacturers, changes in tag numbers and varying usage rates is added, the results may be overstocking, unused parts and increased costs. Another common complication is the amount of manufacturers of different components and parts in use. Information from both offshore and onshore has been stored in various sets of data and different computerized programs, but no common system is at the moment available to sufficiently link them together.

With the new system being developed information from several data sources such as the current information from offshore operations, onshore planning and logistics and other sources such as original equipment manufacturer recommendations, governmental regulations, etc can be implemented in a common system.

The information from offshore personnel involves, among others, condition monitoring data, maintenance needs, offshore stock, current usage rates and some special considerations if applicable. Onshore operations and logistics facilities have several set of data critical to handling spare parts. Such may involve the history of specific parts, such as a pump, usage rate, criticality, reliability, vendors and possible spare part history if the unit has been used for a while. When information regarding governmental regulations, original manufacturer recommendations, transport and delivery times and availability of replacement parts from other manufacturers are added to the same program, there is a foundation for efficient spare part logistics.

With such a system, fully operating and provided with sufficient information, there are possibilities ranging from avoiding unnecessary downtime, overstocking, lack of spare parts and in general having better control of maintenance and spare parts. A person controlling such a system is then able to log into the program for the given drill rig, search for a specific tag number and find a complete overview of the system, part or components condition and need for replacements, spare parts or maintenance. If a component or part needs to be changed, the right part can be sent offshore and installed without the need for time consuming operations between identifying the part and having it sent offshore. Such as controlling which part is to be sent, checking availability, stock levels etc. At the same time the operator is able to check current stock levels and determine if more parts should be purchased. For long term and low criticality parts there can be kept track of their condition, performance and when such items are due for maintenance, be replaced or when new items should be ordered from manufacturers.

The explained system is not operating at the specific drill rig at current date, but is in its final phase before being set to use. Similar systems are in use for most drill rig with success. To have a system fully functioning one is dependent on reliable and accurate data with as much details as possible for as many parts as possible, linked to their respective systems and respective tag numbers. For such a task the parameters discussed in this thesis are used by operators, vendors and other experienced personnel to create a reliable model. In addition there are several set of data from current operations that now are included in one program.

6. Discussion

Large numbers of different spare parts needed for operating a drill rig effectively and safe. Because of these large numbers it is very difficult and time consuming to have a detailed analysis and evaluation of the exact number necessary for each individual part. As explained there is a consideration to make between increased costs by having too many costly spare parts or risk to lack critical parts at inconvenient times. With the spare parts come the costs and problems of overstocking, storage, handling and other logistics. The alternative of lacking spare parts, may, at first, prove more financially applicable, but could very well have serious consequences with effects that by far outweigh the costs of spare parts.

To simplify and aid decision making there are classifications in how different spare parts are categorized, based on their criticality to the operations, similar to how the parameters have previously been suggested to be categorized. Ideally all spare parts and components should be available at all time at the location where it is to be used, but the explained costs, logistics and other problems makes this an evaluation between how fast the part needs to be available and how much one should invest in having the part available. Not all spare parts have to be available at all times and the operations offshore may continue without any severe implications for shorter time periods without such spare parts, in other words, parts of low criticality. There are other parts which may be critical regarding safety and essential to keep operations running and avoiding costly downtime, such parts are classified as high priority spare parts.

The work with having a system to handle the different spare parts require logistics, planning and involvement from several parts involved in the operations. There are costs and logistical challenges with having such a spare part system. For some parts, like high criticality components and systems, the extra cost needs to be accepted into the costs of having a drill rig, if there are no other solutions that will not affect either safety or costs in the long run. Other parts have to be managed and a compromise should be made between cost and benefits with having spare parts available.

In this thesis there have been discussed and analyzed a set of parameters that influence both the need and the importance of the different spare parts. Combining these parameters for a given group or single spare part will give an indication of how important the part or component is, what consequences the failed system lacking the given part has and the timeframe of which the failed part needs to be replaced. To categorize the spare parts by their criticality or importance for the operations, the parameters may be used and their effect, if violated, neglected or ignored, can be studied. By having insight to the criticality and importance the parts are categorized by their effect on operations if they fail or some other way stop working as intended. From such evaluations the spare parts are categorized into high, medium and low criticality. In other words, the importance of the parts depends on their delivery time. From all the parameters on can determine how fast the parts have to be replaced and where and in what numbers they are to be stored. When the rig is moved, the variables in the considerations of the parameters are changed and the process have to start over.

The high criticality spare parts are normally chosen as the ones which with a high probability will lead to either serious damage to personnel, infrastructure or environment or resulting in large costs, as downtime and forced shut downs. Not having such high criticality parts available when they are needed may lead to hazardous situations, injuries, stop in operation or other consequences of high criticality. From conversations with Apply Sørco it has been found that the normal industry standard is that such high criticality parts are given extra considerations with spare parts planning of both numbers and location. The costs involved if the operations are stopped for several days waiting for spare parts to arrive from warehouses combined with the risk for damage and injuries are of such a magnitude that such spare parts are normally kept available at the drilling location at all times in what is regarded as sufficient numbers to handle a failure of the given component. The availability of such spare parts and their convenient location makes it possible to have the broken part replaced or repaired within a number of hours, is an effective alternative compared to several days when transporting equipment for onshore storage facilities.

The medium criticality spare parts are important for operations, but may be stored onshore at warehouses and similar locations. Such parts are available within a number of days and on stock. Such items will not normally result in catastrophic situations or serious downtime, but will be manageable for short timeframes. Because of the mentioned advantages of storing equipment onshore this is a cost effective solution for equipment that is tolerable to not have available within few hours. Such components are often parts that have a low usage rate or a predictable usage rate which enable the possibility of having a set number of parts available in storage facilities. When this storage batch reaches a reorder level, more parts will be delivered resulting in always having a minimum level of parts available at the storage facilities.

The low priority spare parts are as indicated of low importance and may not need to be available either offshore or in storage facilities, but ordered when needed. Normally such low criticality parts are either ordered when needed or a minimum number is kept at the storage facilities similar to the system for medium level parts.

The previously explained problems associated with drill a rig being moved applies to all criticality levels of spare parts. The planned movement and conditions of the rig may influence the decision making in which criticality level a part should be placed. Remote areas with extensive distances of transportation, extraordinary offshore conditions and lack of onshore supporting infrastructure may contribute in affecting the classifications of the spare parts. Such considerations needs to be made for the actual situation the rig is facing and the classification of the spare parts needs to provide a system capable of safe and efficient operations.

The parameters discussed in this thesis are linked together when designing a system and determining the number of spare parts to keep available and where to have the parts stored. The combination of the parameters analysis can be used to determine the importance of a spare part and help categorizing the part as whether a high, medium or low criticality spare part.

The usage rate, with its complications, is of great importance and a very important parameter by industrial standards. The essential part of the usage rate is how long a component will work before it is expected to fail and need replacement. The usage rate needs to be analyzed and evaluated to gain knowledge to lifetimes, probabilities and frequencies of failures for the given component. Both expected data and experience from the use of a component is being used. From this analysis the other parameters are linked to the rate of which a component is worn out. For safety critical equipment there are regulations and policies stating that back-up solutions have to be available if the part should fail. The criticality of the component is then assessed to which the component should be evaluated as a high, medium or low critical component.

The more unpredictable or unreliable the lifetime of a component is the greater is the need for having spare parts available, especially for critical systems and component. A component will always have a certain probability to fail, which often increase with time. At some point this probability should indicate that the component should be changed or a spare part should be available, depending on the criticality and consequence of a failure.

The storage, transport, demand and availability parameters will on the next level be affected and affect the need for spare parts indicated by the usage rate. If the evaluation of the usage rate indicates that there will be a high usage of critical components, one will either need to store enough components or have a fast and reliable manufacturing and transportation system. The unpredictability in demand and usage of spare parts contribute to making the model either vulnerable to high consumptions or overly conservative in some periods and conditions.

Finally the original equipment manufacturing recommendations and costs should aid in assessing the various alternatives. There are large costs involved with having spare parts available, ordering when needed and especially the situations to be avoided as downtime, fines, and damage to personnel, equipment and environment. Costs will always play an important role in decision making, but the consequences of serious accidents encourage investments in safety improving measures.

From the practical example with information from a rig company operating in the North Sea it shows that the parameters mentioned in this thesis are being used with available data on the specific component in a computer based program to handle spare parts for drill rigs. The mentioned computerized system which enables keeping track of maintenance schedules, usage history and data, stock levels and other important information to spare part logistics will aid in having an effective spare part system for offshore drill rigs. It is clear that the parameters discussed are included in the process, among other sources of data to create an efficient spare part model.

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